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Economic benefits of arsenic removal from ground water — A case study from West Bengal, India

*Joyashree Roy**

Department of Economics, Jadavpur University, 188, Raja S.C. Mallik Road, Jadavpur, Kolkata 700 032, India

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ABSTRACT

People living in almost 50% of the districts in West Bengal are exposed to arsenic contaminated water. This paper seeks to estimate the economic costs imposed by arsenic-related health problems. We use data from a primary survey of 473 households carried out in the districts of North 24 Parganas and Midnapore. We take into account household actions to either decrease the exposure of family members to unsafe water or to alleviate the health effects of consuming arsenic-contaminated water. This allows us to assess the benefits of arsenic-safe water by estimating a three equation system that includes averting actions, medical expenditures and a sickness function. We find that by reducing arsenic concentration to the safe limit of 50 μg/l, a representative household will benefit by Rs 297 ($7) per month. The current cost of supplying filtered piped water by the Kolkata Municipal Corporation to households is Rs 127 ($3) per month per household. Thus, investing in safe drinking water is economically feasible and households are willing to pay for such investments if made aware of the effective gain in welfare. Poor households, who make up the highest proportion of arsenic-affected households and incur the largest number of sick days, will be major beneficiaries of such investments.

1. Introduction

Fifty percent of the districts in the state of West Bengal in India are exposed to arsenic contaminated water (Guha Mazumder et al., 1998). A large number of people have been diagnosed with symptoms of arsenic poisoning even though much of the at-risk population has yet to be assessed for arsenic-related health problems (Guha Mazumder et al., 2000). Evidence of arsenic contamination was first identified in the 1980s, but by the mid-1990s it was clear that this constituted a public health crisis.

Arsenic is a shiny metalloid that dissolves in water. Humans ordinarily cannot detect, i.e., without water testing through appropriate technologies, its presence before it is too late. We can neither see, nor taste, nor smell whether the water we drink is contaminated with arsenic compounds. A large number of studies have shown that arsenic in drinking water can cause bladder, lung, kidney, liver and skin cancer. Arsenic can harm the central and peripheral nervous systems as well as heart and blood vessels, and can cause serious skin problems. It may also cause birth defects and problems in the reproductive system. In a developing country, attribution of medical expenditure to arsenic-related diseases imposes an extra burden on the already overburdened public provision of medical care. While other parts of India also have arsenic contamination, such contamination is quite acute in West Bengal.

The basic source of arsenic in West Bengal is geological — the arsenic is released to groundwater under naturally occurring aquifer conditions. Arsenic is generally detected in very shallow aquifers – between 30–70 meters – while deeper aquifers tend to be arsenic free. Over the last two decades in West Bengal, untreated tube well water was heavily promoted as a safe alternative to microbiologically unsafe untreated

* Tel.: +91 33 24257382, +91 33 64147760; fax: +91 33 24127905.
E-mail addresses: jroy@cal2.vsnl.net.in, joyashree@yahoo.com.

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surface water. Further, almost no restriction was imposed on withdrawal of underground water for irrigation. Massive and extended use of groundwater (Central Ground Water Board, 1999) for agriculture resulted in the lowering of the water table, leading to the mixing of arsenic in the sulphide rock with intruding oxygen, which subsequently dissolved in water that was used for drinking purposes.

While several studies have looked into the issue of arsenic contamination, most existing studies (Chakraborti, and Saha 1987; Das et al., 1994, 1996; Dang et al., 1983; Garai et al., 1984; Guha Mazumdar et al., 1984; Guha Mazumder et al., 1988, 1998, 2000; Guha Mazumdar, 2001) explore geological and climate features, scale of the problem in terms of population coverage, the intensity and variety of health problems, and the technologies for arsenic removal. None of the studies cited above addresses the economic dimension to welfare loss and hence the associated costs and benefits of arsenic contamination and removal. A recent study by Ahmad et al. (2002) attempts to assess the WTP for piped water in arsenic-affected areas of Bangladesh.

The main objective of this paper is to assess the costs of arsenic contamination to households. In other words, this paper seeks to quantify the benefits to households in West Bengal of using arsenic-free water. Currently various plans are in place to solve the problem of arsenic contamination. However, while the costs associated with such plans are known, little is known about the value of benefits. This paper addresses the basic issue of good quality (that is, arsenic-safe) water as a scarce resource. Within such a context, we analyze the household demand for arsenic-safe drinking water.

2. Theoretical framework

There is a vast literature (Grossman, 1972; Freeman, 1993; Courant and Porter, 1981; Cropper, 1981; Gerkin and Stanely, 1986; Harrington and Portney, 1987; Murty et al., 2003; Roy and Sahu 2004, Roy et al., 2004) that uses an understanding of the behavioural responses of households to poor environmental quality in order to value the benefits of improvement in quality. This study similarly uses the household health production function model consisting of a household health production function and household demand function for mitigating and averting activities to estimate the benefits from a decline in arsenic concentration in ground water.

Households purchase market goods and/or allocate leisure time to produce consumable goods which give them utility. Since poor water quality can have a profound effect on human health, rural households often undertake various averting and adaptive actions to either decrease the exposure level of their family members to unsafe water or to alleviate the health effects of consuming arsenic-contaminated water. In West Bengal, households spend time or money to access arsenic-free water and medical treatment. Household actions to avert, mitigate and adapt to arsenic-contaminated ground water enter the utility function along with market goods.

Following existing literature, particularly Freeman (1993), we consider an individual utility function of the form

$$U = U(X, L, S) \quad (1)$$

where X represents expenditures on all non-health related goods, L represents consumption of leisure and S the time spent sick.

$U_X > 0, U_L > 0, U_S < 0.$

We assume that the sickness of an individual depends on exposure to pollution due to arsenic contamination, p, the adaptive or mitigating activities such as medical treatment b, stock of health capital, h, and stock of human capital, i.e., education, e. The health production function can be written as:

$$S = s(p, b, h, e) \quad (2)$$

where $S_b<0$, $S_p>0$ and S_{bb}, $S_{pp}\neq 0$.[1]

One of the determinants of health status from arsenic contamination is the exposure or dose (cumulative or one time) of arsenic. So the variable, p, mentioned in Eq. (2) represents the exogenous environmental condition that depends on the concentration of arsenic in water, c, and the extent of averting[2] activity a, undertaken by the household to avoid or reduce exposure to pollution.

$$p = p(c, a) \quad (3)$$

$p_c>0$, $p_a<0$

and by substitution

$$S = s(c, a, b, h, e) \quad (4)$$

$S_c>0$, $S_a<0$, $S_b<0$, $S_h<0$, $S_e<0$.

Given the utility function in Eq. (1) the individual chooses X, L, a and b in such a way so as to maximize utility subject to the full-income budget constraint (Freeman, 1993).

$$I = I^* + w(T - L - S) = X + P_a.a + P_b.b \quad (5)$$

where, P_a=Price of averting activities, P_b=Price of adaptive (medical) activities, I^*=Non-wage income, X=Expenditure on other goods and T is Total Time. Time Constraint is $T-L-S(c, a, b)=0$.

[1] Assumption of non- zero second order derivative implies non-linearity in effect of medical expenditure and arsenic concentration on sickness. There is no unanimity about the direction of these effects that can be gleaned from dose response studies in arsenic literature (Adair et al, (2006), Chowdhury et al. (2000), ahman et al. (2003), Chakraborti et. al. (2001). However, there are studies which do not rule out possibility of threshold and non linearity and possibility of U-shaped relation (Commission on Life Sciences, 1999). Though USEPA accept (London Group, http://www.es.ucl.ac.uk/research/lag/as/) linearity, our assumption of non linearity is more in line with other studies on impact of pollution on health and is grounded in curvature property of the production function, shapes of pollution abatement cost and damage cost curves and some field observations.

[2] Averting costs are incurred to avoid the health impact. They reflect the cost of alternative action to achieve the same utility from the same end use activity, that is, drinking water. Mitigation costs are incurred to reduce damage after the exposure has occurred. We also refer to mitigating costs as adaptive costs.

To get the health impact of a change in arsenic concentration, c, in drinking water, we take the total derivative of the health production function:

$$\frac{ds}{dc} = \frac{\partial s}{\partial a^*}\frac{\partial a^*}{\partial c} + \frac{\partial s}{\partial b^*}\frac{\partial b^*}{\partial c} + \frac{\partial s}{\partial c} \tag{6}$$

Eq. (6) can be rearranged as follows:

$$\frac{\partial s}{\partial c} = \frac{ds}{dc} - \frac{\partial s}{\partial a^*}\frac{\partial a^*}{\partial c} + \frac{\partial s}{\partial b^*}\frac{\partial b^*}{\partial c} \tag{7}$$

where, a^* and b^* are the optimal values of averting and adaptive actions.

$$a = a(w, P_b, P_a, c, I^*, h, e) \tag{8}$$

$$b = b(w, P_b, P_a, c, I^*, h, e). \tag{9}$$

These optimal values are obtained by maximizing the utility function subject to the constraint (5) (Freeman, 1993). The first order conditions with respect to change in arsenic concentration c, (Freeman, 1993; Murty et al., 2003) can be combined with Eq. (7) to show that:

$$W_c = w\frac{\partial s}{\partial c} + Pb\frac{\partial b^*}{\partial c} + Pa\frac{\partial a^*}{\partial c} - \frac{\frac{\partial u}{\partial s}}{\lambda}\frac{\partial s}{\partial c}. \tag{10}$$

Expression (10) says that MWTP (W_c) for health improvements related to reductions in arsenic concentration, c, is the sum of the observable reductions in the wage cost of illness, medical expenditure, averting activities and the monetary equivalent of the disutility of illness. The term $w\frac{\partial s}{\partial c}$ includes both actual and lost wages and lost leisure time valued at the wage rate.

To estimate Eq. (10) we estimate the health production function (4), and demand functions for a^* and b^* represented by Eqs. (8) and (9) as a system of simultaneous equations. This requires information on a) expenditure on adaptation such as medical expenditure, b) wage loss due to sickness, c) averting expenditure such as money or labour time spent for fetching water, d) the socio-economic information on households, and e) information on arsenic contamination in sources of drinking water.

Ideally, it is best to estimate this system of equations using individual-level information. However, in practice it is difficult to get individual-level information especially on averting and medical expenditure because these are often household-level decisions in rural families and avertive expenditure in particular may be indivisible at the individual level. Consequently, several studies on the health production function have used household-level information after controlling for family size in the estimation (Murty et al., 2003; Dasgupta 2004). This is the approach we take. Another practical change that we make in the empirical model is in the estimation of the avertive and adaptive demand equations. Because it is hard to assign prices to such actions, these equations are estimated with left-hand side variables reflecting expenditure.

3. Sample selection and data collection

The data for this study is based on a household-level survey of 473 households carried out in the state of West Bengal during 2002–2003. As the first step towards selection of the representative sample, we narrowed down the scope of our survey from a total of 18 districts to 8 districts that have arsenic-affected blocks in them. We expect the averting and adaptation behaviour of the households to vary with the concentration level. Thus, we identified the highest and lowest-level of arsenic concentration across the 8 affected districts. Out of 8 districts we observed that North 24 Parganas has the largest number of arsenic-affected blocks across all districts in West Bengal and has the maximum range of variation in concentration level of arsenic in ground water (3370 μg/l to 51 μg/l levels). These also reflect the maximum and minimum levels for the state. Thus North 24 Parganas was identified for conducting the survey.

To arrive at the household-level units from the districts of 24 Parganas, we followed several steps. The first was to identify blocks and then villages with habitations that had the highest range of concentration variation. We arranged the blocks in a descending order of maximum arsenic concentration across all habitations. We took 7 out of 14 blocks with concentration levels greater than 500 μg/l and one out of 6 blocks with concentration levels less than 500 μg/l in order to get the maximum variation in concentration levels. Arsenic concentration wise distribution of blocks is right skewed with maximum number of blocks in the concentration level higher than 500 μg/l and the curve peaks at maximum concentration of 500 μg/l. Those below 500 μg/l are mostly have very low level of concentration around safe limit. So larger proportion of blocks with concentration level higher than 500 μg/l make the sample representative.

At the next stage, while selecting the villages in the blocks we followed the same procedure as block selection, using

Table 1 – Study sites

Sl no.	Block	Max conc. (μg/l)	No. of surveyed villages	No. of habitations surveyed	No. of households surveyed
1	Amdanga	3370	1	1	14
2	Habra II	1945	9	33	88
3	Deganga	1600	13	54	107
4	Baduria	1250	10	59	111
5	Haroa	1060	8	29	85
6	Gaighata	800	7	23	46
7	Habra I	650	1	4	9
8	Barasat	330	1	6	13
	Total		50	209	473
Control	Midnapore		1		50

Source: Public Health Engineering Department (PHED).

Table 2 – Socio-economic status of the surveyed households

Income group	Monthly income range in Rs	Percentage of households	Average educational attainment (years of schooling)	Occupational structure		
				Percentage of agricultural households	Percentage of non-agricultural households	Percentage of both
I	Low Income Group (0–2000)	37%	4.11	47%	36%	17%
II	Middle income group (2000–6000)	53%	4.5	37%	34%	30%
III	High Income Group (6000 and above)	10%	8.05	9%	52%	39%

Source: Field survey.

village-level concentration information. A control village – Midnapore – which is arsenic free was also chosen. Table 1 shows the number of villages that have been chosen from each block. The survey was planned in such a way that it would cover at least one-third of the habitations. We covered a little less than 50% of the villages but a little more than 50% of the habitations.[3]

In the eight selected blocks, there are 278 villages with arsenic concentration much above the safe limit (50 μg/l). The villages together have 649 tube wells[4] for which arsenic concentration measures are recorded by the Public Health Engineering Department (PHED). Villagers have been made aware of wells with safe drinking water. Tube wells marked with red were identified as unsafe.

Household selection was done through random sampling. Surveyors visited all chosen habitations and identified the shallow tube wells for which concentration levels are reported. They listed the households in the command area of each water source and randomly selected the number of households that they would interview. The number of households surveyed in each command area varied depending on the size of the command area.

The questionnaire which has been used for household interviews is divided into eight sections. An attempt was made to elicit individual-level as well as household-level information. The first section deals with socio-economic details, including basic income expenditure data. Sections two to four deal with the information relating to a household's demand for quality water. The fifth and sixth sections give us the sickness, that is, medical treatment details of family members arising due to both arsenic as well as non-arsenic diseases. The seventh section contains awareness details, including questions on the nature and number of arsenic-related awareness programmes conducted in the neighbourhood.

A key aspect of the survey was to elicit arsenic disease related information through both direct questioning of the households and the observations of the surveyors who had undergone preliminary training at an Arsenic clinic in Kolkata. In the study area, households were exposed to arsenic-awareness campaigns. Many also knew about their diseases because of visits to arsenic clinics. From field-level observation we identified seven categories of arsenic-related diseases: *melanosis*, *keratosis*, ulcer, vascular disease, lung problem, *polyneuropathy*, and *arsenicosis*. It was observed furthermore that a large percentage of households suffered from *gastroenteritis* and occasional bouts of *diarrhea* and dysentery. To check whether these diseases were also a fallout of prolonged exposure to arsenic above the safe limit of 50 μg/l, a control village with similar socio economic and demographic features but within the safe limit of arsenic concentration was surveyed. It was found that diarrheal diseases were equally rampant in the arsenic-free area. Moreover, medical practitioners informed us that there is no substantive evidence of a positive correlation between high levels of arsenic concentration in drinking water and *gastroenteric* malfunctions. In the questionnaire, separate questions were posed on arsenic-related as opposed to non-arsenic related diseases.

4. Households in the study area

Socio-economic and demographic features of the surveyed households are given in Table 2. The households have been classified by income categories. The lowest income category with households having monthly income levels equal to or less than Rs 2000 represents the BPL (below poverty line category) followed by the middle and higher income categories.

The majority (53%) of households interviewed reported income varying between Rs 2000 and Rs 6000 with 37% of households in the BPL category while 10% are in the higher income group. This is comparable to the state-wide income distribution pattern.[5] Educational attainments rise with income level. The low-income group has the highest percentage of households engaged in agricultural activities whereas the high-income group has the highest percentage of families engaged in non-agricultural activities. The middle-income families on the other hand are found to engage in both agricultural and non-agricultural activities in almost equal proportions.

Table 3 shows the maximum and minimum concentration levels of arsenic at the block level and the percentage of the population of each block accessing drinking water from arsenic-free sources. Table 4 provides a number of other details by income class. While the proportion of users of arsenic-free water is almost the same (80%, Table 4) for lower and middle income class households, it is higher (90%) for the upper income class. The lower income households suffer the most from both arsenic and non-arsenic diseases, but have

[3] The lowest administrative unit for which concentration level is available is the 'habitations' in the villages. Habitations are a cluster of houses forming a residential neighbourhood.

[4] A detailed list is available with the author.

[5] As per government of India estimates, the percentage of rural population living below the poverty line in West Bengal has fallen from 73.16 in 1973-74 to 31.85 per cent in 1999-2000 (Planning Commission, 2002).

Table 3 – Households currently using arsenic-free sources of water for drinking

Sl no.	Blocks	Maximum arsenic concentration (μg/l)	Minimum arsenic concentration (μg/l)	Percentage of household using arsenic free water
1	Amdanga	3370	51	70%
2	Habra 2	1945	51	72.33%
3	Deganga	1600	51	64.86%
4	Baduria	1250	55	95.29%
5	Haroa	1060	52	50.00%
6	Gaighata	800	54	53.85%
7	Habra 1	650	57	77.78%
8	Barasat	330	51	30.84%

Source: Field survey.

less ability to spend on the maintenance of health as reflected through relatively lower medical expenditure and the distance-travelled for accessing health services. The poor also have a higher number of sick days on average. The majority of the households are aware that the quality of water they are using is the main cause of arsenic-related diseases.

From the random sample of 473 households with a total number of 2432 individual members of all age groups, a total of 871 (36% approx.) members reported that they suffered from some kind of disease over the recall period of 1 year while only 115 members reported suffering from arsenic-related disease.[6] Analysis of these observations show 4.7% of all the sample households experience arsenic-related diseases, where as this percentage is 13% if we take the proportion between arsenic affected households and households reporting sickness of any kind. It is worth noting because it reflects additional adverse health impact of arsenic contamination on sick households. Households with poor health report higher incidence of arsenic related disease as we observe. Extrapolating from this information based on the random sample survey, it can be said that the chance of any individual living in surveyed blocks to be affected by arsenicrelated disease is 0.047 while those of a diseased person in the same area chance of getting arsenic-related disease is higher and is found to be 0.13.

Table 4 shows that 21% of arsenic-affected households out of the total households surveyed are in the lower income group. However, if we consider the total number of households with arsenic patients, 63% are from the lower income group while 33% and 4% respectively are from the middle and higher income groups. Household responses show that on an average a sick person suffering from an arsenic-related disease works for 2.73 h compared to a healthy person who works beyond 8 h per day.

5. Empirical estimation of production and demand functions

As stated in Section 2, we attempt to estimate the welfare gain by the households from arsenic removal through the estimation of MWTP or the avoided cost of wage loss due to sickness, adaptation cost through medical expenditure, and averting cost. We estimate a system of simultaneous equations consisting of three equations in three endogenous variables: sick days, medical expenditure, and averting expenditure.

The system of simultaneous equations with three equations in three endogenous variables is:

$$\ln Y_1 = \sum \beta_{1j} \ln X_{1j} + \sum \beta_{1j} \ln Y_{1j} + u_1 \quad (11)$$

$$\ln Y_2 = \sum \beta_{2j} \ln X_{2j} + \sum \beta_{2j} \ln Y_{2j} + u_2 \quad (12)$$

$$\ln Y_3 = \sum \beta_{3j} \ln X_{3j} + \sum \beta_{3j} \ln Y_{3j} + u_3. \quad (13)$$

where Y and X show the vector of endogenous and exogenous variables appearing in ith (=1, 2, 3) equation. The explanatory variables in Y and X vectors are shown by *j*. We take the double log form of the equations based on our assumption (mentioned in Section 2) of non-linearity of the underlying functions. Eq. (11) represents the household health production function expressing the health status given in terms of number of sick days in a household. Eqs. (12) and (13) represent household demand for adaptive expenditure and averting activity.

Table 5 provides the list of variables (*j* in Eqs. (11)–(13)) used in estimation of the three equations. Each of the equations is expressed as a function of exogenous and instrumental variables representing household and local water quality characteristics. We estimate the parameters for the three income groups by pooling the data across the three income groups (separate estimates for the three income groups are shown in the Appendix) using appropriate dummy variables. The estimation has been done using the log linear version of the equations. Since endogenous variables appear among the explanatory variables set, we have made use of the Three Stage Least Square (3SLS) estimation procedure.

We briefly describe below the construction of selected variables used in the estimation.

5.1. *Sick days in the households (msickd)*

The number of days per month spent sick by the members in each household is used as a measure of health status. The cause of sickness may be arsenic-related diseases, non-arsenic related diseases, or both. This information was obtained by directly asking the respondent about the total days of sickness in the recall period of 1 year for each adult and child member in that household. Sick days are converted to per month to be consistent across all variables.

5.2. *Medical expenditures (mmedexp)*

This refers to household total medical expenditure for all the members for all kinds of diseases, both arsenic and non-arsenic. It was difficult to obtain separate medical expenditures by disease during the survey.

[6] The survey identified the most prevalent diseases related to arsenic of the households in the surveyed areas .The list of diseases in the questionnaire separated out arsenic-related diseases from non- arsenic diseases.

Table 4 – Total medical expenditure

Characteristics/income range	Low income (0–2000)	Middle income (2000–6000)	High income (6000 and above)
% using arsenic-free water	80	80	90
Average total years of schooling for the household	17	24	49
% of monthly expenditure on food	76	75	69
% of households suffering from arsenic diseases	21%	7%	5%
% of households suffering from non-arsenic diseases	100%	72%	98%
Average distance travelled to collect water in km	0.18	0.11	0.13
Average time spent per day in minutes	19	17	22
% of households considering arsenic contamination as major cause of health effects	46	52	47
Average number of sick (including all kinds of sickness) days in a month	9.5	7.8	7.7
Average per capita medicine expenditure for non-arsenic diseases (Rs/month)	0.95	1.5	13.38
Average per capita expenditure on medicine for arsenic diseases (Rs/month)	1.58	12.96	29.17
Average time spent (in minutes/month) by an household to visit hospital for non-arsenic disease	27.84	37.01	71.68
Average time spent (in minutes/month) by an household to visit hospital for arsenic-related disease	33.07	47.41	2.50
Average distance travelled to medical facility for non-arsenic disease (km/month)	2.32	6.00	15.94
Average distance travelled to visit medical facility for arsenic disease (km/month)	6.95	11.88	18.75

Source: Field survey.

5.3. *Averting activities (avert)*

Avertive activities are defined as the time spent by a household each day to collect arsenic-free water. Households were asked questions regarding the approximate distance they travel and the time spent for collection of arsenic-free water. On the basis of information on hours per day spent on collecting water, we find that the average household spends about 7 working days per month on water collection. The averting activity is converted from physical units of number of days and distance travelled to monetary values. The distance travelled is converted into units of time and monetized using the wage rate for female members.

5.4. *Household Exposure Index (hexpa)*

The Household Exposure Index is arrived at by taking the product of arsenic concentration level (μg/l) for the habitation and water consumed by each household per month. The household level water consumption varies by gender and age. We have considered water intake daily by adult male, female and children of 6, 4, and 2 l respectively. The Arsenic Concentration Index for each habitation is available from the PHED database. The product of water consumed and the arsenic concentration level in the water is aggregated over all members in the family.

5.5. *Health Stock Index (nonarsd)*

The Index for Health Stock, which measures the health capital of the household, is the weighted sum of the number of non-arsenic diseases that family members have suffered over the recall period of six months. Weights are given by the ranks to show the relative expensiveness of the disease. For example, chronic diseases such as asthma have a higher numeric rank compared to diseases such as flu. The higher the value, the worse is the health stock.

5.6. *Education (totedu)*

The literacy level of households is the total number of years of schooling that the family members have had which shows the household-wise social capital as an index of awareness level of the households. This has been constructed from member-wise details of educational attainment.

5.7. *Major cause (majcau)*

This is a binary variable reflecting the awareness level of the respondent of the household about the arsenic contamination in the water used and its health effects.

5.8. *Number of persons sick in households (nopersick)*

This gives a count of persons sick in the households per month. This variable is included as a scale factor since we use the total number of sick days as another explanatory variable.

6. Results and discussions

Parametric estimates of the structural Eqs. (11), (12) and (13) using 3SLS estimation procedure are provided in Table 6 for the data set pooled over all income groups. (The Appendix tables A1–A.3 report results for the three income groups separately).

The results in Table 6 show that the number of sick days increases with household exposure to arsenic and decreases with increasing medical expenditure. However, the coefficients are not statistically significant. Averting activities show a significant but positive relation to sick days which appears to

Table 5 – Equations and variable descriptions

Endogenous variables	Represented by variable/ (Equation)	Appears in equations/models with expected signs			
		Pooled	Income group I	Income group II	Income group III
Number of sick days in a month	Msickd (EQ1)	EQ1	EQ1	EQ1	EQ1
Monthly household medical expenditure	Mmedexp (EQ2)	EQ2	EQ2	EQ2	EQ2
Monthly averting expenditure	Avert (EQ3)	EQ3	EQ3	EQ3	EQ3
Explanatory variables					
Endogenous variables					
Number of sick days in a month	Msickd	EQ2 (+), EQ3 (+)	EQ2 (+), EQ3 (+)	EQ2 (+), EQ3 (+)	EQ2 (+), EQ3 (+)
Monthly household medical expenditure	Mmedexp	EQ3 (–)	EQ3 (–)	EQ3 (–)	EQ3 (–)
Monthly averting expenditure	Avert	EQ1 (+), EQ2 (–)	EQ1 (+), EQ2 (–)	EQ1 (+), EQ2 (–)	EQ1 (+), EQ2 (–)
Exogenous variables/instruments					
Number of persons sick in a household	Nopersick	EQ1 (+)	EQ1 (+)		
Total age of the members in a household	Tage	EQ1 (+), EQ2 (+)	EQ1 (+), EQ2 (+)	EQ1 (+), EQ2 (+)	EQ1 (+), EQ2 (+)
Monthly household income (ÿg)			EQ3 (+)		
Monthly household expenditure on food	Mexpf	EQ1 (–),EQ2 (–)	EQ2 (–)	EQ2 (–)	EQ2 (–)
Health Stock Index	Nonarsd	EQ1 (+), EQ2 (+)	EQ1 (+), EQ2 (+)	EQ1 (+), EQ2 (+)	EQ1 (+), EQ2 (+)
Family size	Fz	EQ1 (?)	EQ1 (?)	EQ1 (?)	EQ1 (?)
Household's exposure to arsenic	Hexpa	EQ1 (+), EQ2 (+), EQ3 (+)	EQ1 (+), EQ2 (+), EQ3 (+)	EQ1 (+), EQ2 (+), EQ3 (+)	EQ1 (+), EQ2 (+), EQ3 (+)
Distance travelled to fetch arsenic free water	Dist	EQ1, EQ2, EQ3	EQ1, EQ2, EQ3	EQ1, EQ2, EQ3	EQ1, EQ2, EQ3
Household time spent for fetching Aarsenic-free water	Time	EQ1, EQ2, EQ3	EQ1, EQ2, EQ3	EQ1, EQ2, EQ3	EQ1, EQ2, EQ3
Agriculture as primary source of income	Agr	EQ3(?)		EQ3 (?)	EQ3 (?)
Water contamination as major cause of disease	Majcau	EQ2 (+), EQ3 (+)	EQ2(+)	EQ2 (+), EQ3 (+)	EQ2 (+), EQ3 (+)
Dummy for income group 1	Inccode1	EQ1 (?), EQ2 (?), EQ3 (?)			
Dummy for income group II	Inccode2	EQ1 (?), EQ2 (?), EQ3 (?)			

have a perverse sign. It needs to be mentioned that the sick days include all types of diseases and not arsenic-related diseases exclusively. Hence, averting activities targeted at getting arsenic-free water may not show a reduction in the number of sick days. However, the causality of the impact of sick days on averting behaviour (Eq. (3)) shows the correct relation. It is expected that households will adopt more averting activities if they experience more sickness.

The second equation explains the determinants of adaptive behaviour represented by medical expenditure. Medical expenses rise as hypothesised with household exposure to arsenic and number of sick days and decrease if averting activities increase. All the relevant coefficients are statistically significant.

Eq. (3) shows that averting activity increases and is statistically significant if household exposure to arsenic increases.

7. Estimating welfare gain from arsenic removal

Table 6 presents estimates of the components of the Eq. (10) (Section 2). Given the variable descriptions and their constructions in Table 5 and corresponding text, Eq. (10) can be rewritten as:

$$W_c = \mathrm{MWTP} = w\frac{\partial(\text{sickdays})}{\partial(\text{exposure to arsenic})} + \frac{\partial(\text{Medical expenses})}{\partial(\text{exposure to arsenic})} + \frac{\partial(\text{Averting activity})}{\partial(\text{exposure to arsenic})}.$$

$$W_c = \mathrm{MWTP} = w\frac{\partial(\text{msickd})}{\partial(\text{hexpa})} + \frac{\partial(\text{mmedexp})}{\partial(\text{hexpa})} + \frac{\partial(\text{avert})}{\partial(\text{hexpa})} \quad (14)$$

The MWTP is estimated for all income groups (pooled data) and the three different income groups separately and are presented in Table 7. The pooled results use parameter estimates from Table 6. The results for the different income groups are based on separate regressions, which are presented in the Appendix (A1–A3).

In order to calculate the MWTP in Table 7, we adjust the estimated parameters in Table 6 since these estimates are in log linear formulation. Thus, the reported average MWTPs in Table 7 are arrived at by adjusting each of the coefficients at mean values of the variables. In addition, the first coefficient is multiplied by the wage rate/month to arrive at the final MWTP values.

Some of the parameter estimates used in Eq. (14) to arrive at the welfare calculation in Table 7 are statistically insignificant even at the 10% level of significance (Tables 6, A1–A3). Recent studies by others such as Murty et al., (2003) and Gupta (2006) have ignored the statistical significance of coefficients in estimating welfare gain and loss. However, in Table 7 we report estimates of welfare gains when the coefficient values are set at their actual estimated values and also set at zero if they are not significantly different from zero.

The first coefficient in Eq. (14), i.e., the change in sick days with changing arsenic concentration is statistically insignificant and so we assume its value to be zero. Based on this, our estimates suggest that the welfare gain from a reduction in 1 μg per litre of arsenic for the pooled sample is Rs 0.49 per household per month.

Table 6 – Parameter estimates of model for pooled data

Model/equation/ Variables Pool	Expected sign	Parameter value	t-value
EQ1 (sick days)			
Constant	?	−19.43	−1.57*
Nopersick	+	0.86	4.19***
Avert	−	0.27	2.34***
Tage	+	7.23	1.87**
Mexpf	−	−0.03	−0.12
Nonarsd	+	2.03	1.77
Fz	?	−6.62	−1.62*
Hexpa	+	1.23	1.08
Inccode1	?	−1.39	−0.88
Inccode2	?	1.53	0.44
R^2	0.41		
EQ2 (medical expenditures)			
Constant	?	−7.53	−1.94***
Msickd	+	0.75	6.66***
Avert	−	−0.58	−7.19***
Mexpf	+	0.07	0.46
Tage	+	−0.41	−0.36
Nonarsd	+	0.69	0.92
Majcau	+	1.04	3.15***
Hexpa	+	1.30	3.23***
Inccode1	?	4.57	2.40***
Inccode2	?	5.15	1.54*
R^2	0.47		
EQ3(avertive expenditures)			
Constant	?	−10.52	−2.41***
Msickd	+	0.79	3.77***
Mmedexp	−	−1.07	−4.28***
Agr	?	−0.38	−0.92
Majcau	+	1.18	2.30***
Hexpa	+	1.38	2.26***
Inccode1	?	4.57	2.40***
Inccode2	?	5.15	1.54*
R^2	0.0074		

Source: Author's estimates.
***Significant at 1% level, **significant at 5% level and *significant at 10% level.

If the arsenic concentration is reduced to the safe limit of 50 μg/l, the benefits to each household is Rs 297 per month while the annual household gain is Rs 3573. The same benefits are Rs 161 per month and Rs 1934 per year if the arsenic concentration is reduced by half of what it is right now.

These figures need to be interpreted with some caution. We arrive at these values of welfare gain by proportionally scaling up econometric estimates of the gain from a marginal (1 unit) change. It is possible that this linear scaling-up is incorrect, but with no other information, we assume that this relationship between dose and medical and avertive expenditure holds at different levels of doses.

We also look at the welfare gains for different income groups by estimating the equations separately for poor, middle-income, and rich groups. We find that for the high income group all the three coefficients used in Eq. (14) are statistically insignificant, which implies that the minimum MWTP is close to zero. This may be because the higher income group is already less adversely affected by arsenic and will gain relatively little from arsenic removal. However, we also estimate 95% confidence intervals to show a range within which the welfare gains may fall in Appendix A4.

It is useful to compare the findings of this study with recent estimates of willingness-to-pay to reduce arsenic in Bangladesh (Ahmad et al., 2002). While our study shows that averting expenditure ranges from Rs. 11.36–14.46 per month per household in West Bengal, in Bangladesh the comparable values are Taka 12.6–16.3 per month. However, the MWTP from our revealed preference study which takes into consideration all three components – sick days, medical expenditure and averting expenditure – is much higher compared to the stated preference WTP value obtained by Ahmad et al. (2002).

The annual welfare gain estimated for arsenic removal is higher than the estimated gains for air and water pollution removal (Murty et al., 2003, Jalan et al., 2003, Gupta, 2006). The reason might be attributed to the fact that Gupta's study does not include averting expenditure while Jalan et al., (2003) study considers averting expenditure only and Murty et al. (2003) study has a lower estimate of the number of sick days (2 days per month) compared to the present study (8 days per month). Arsenic-affected households report a relatively larger number of sick days per month compared to other kinds of pollution-induced sickness which is not counter factual. This may be partly because the study area has a very high level of arsenic concentration with a maximum concentration of up to 3370 μg/l (see Table 1).

If we consider the fact that the chances of getting an arsenic-related disease in an arsenicprone zone is 0.047 while the total population size is 7.2 million for the district, then the total number of people with the likelihood of arsenic-related sickness is 3,38, 400. The total annual welfare gain to households (considering the household size in the pooled sample in Table 7 and the likely number of arsenic-affected people) from bringing down the arsenic concentration to a safe limit of 50 μg/l in the district will therefore be Rs 229 million.

8. Conclusions and policy implications

The study aimed to assess the economic costs of arsenic-related health problems. The scope is limited to one district in West Bengal but the results are comparable with other studies. It is useful to know from this study that the chance of a person living in North 24 Parganas district of West Bengal getting an arsenic-related disease is quite low at 0.047. But if we estimate the cost burden to society in aggregate monetary terms, this works out to Rs 229 million in North 24 Parganas. It is important for policy makers to know that reduction in arsenic concentration in water to the safe limit through technological and policy intervention can generate such large health benefits. The policy relevance of this estimate of the health cost of arsenic contamination is noteworthy because, if guided only by physical measures such as the probability of getting arsenic-related disease, which is low, decision-makers may

Table 7 – Household characteristics and estimates of welfare gain

	Income groups			
	Income<=2000	Income>2000<=60,000	Income>6000	Pooled
Average characteristics				
Income/month (Rs) w	1431.98	3389.53	10,906.83	3731.16
Family size (Number)	4.45	5.51	6.73	5.27
Sick days/month (number)	9.50	7.82	7.75	8.16
Medical expenditure/month (Rs) *	205.58	297.68	168.21	234.53
Averting expenditure/month (Rs)	13.02	11.36	14.46	12.08
Concentration of arsenic (μg/l)	688.90	627.44	610.74	655.61
Welfare gain (MWTP, W_c)				
Monthly welfare gain from reduction of arsenic concentration by 1 μg/l (Rs)	0.56 (0.52)	1.02 (0.77)	3.65 (0.00)	2.39 (0.49)
Monthly welfare gain from reduction of arsenic concentration by half of the current level (Rs) **	192.69 (179.23)	319.52 (242.49)	1115.73 (0.00)	784.81 (161.18)
Monthly welfare gain from reduction of arsenic concentration to safe limit of 50 μg/l (Rs) **	357.42 (335.52)	588.12 (446.35)	2048.77 (0.00)	1449.91 (297.77)
Annual welfare gain from reduction of arsenic concentration by 1 μg/l (Rs)	6.71 (6.3)	12.00 (9.28)	43.84 (0.00)	28.73 (5.90)
Annual welfare gain from reduction of arsenic concentration by half of the current level (Rs) **	2312.69 (2150.8)	3834.27 (2909.92)	13,388.73 (0.00)	9417.69 (1934.12)
Annual welfare gain from reduction of arsenic concentration to safe limit of 50 μg/l (Rs) **	4289.8 (3402.27)	7057.44 (5356.15)	24,585.25 (0.00)	17,398.89 (3573.23)

Note: Figures within brackets show the results if values of the parameters that are statistically insignificant are taken as zero.
Source: Author's estimates.
* This includes expenditures made on medicine (Table 4) and other non-medical costs (e.g., doctor's fee, hospital visitation expenses, hospital transfer expenditure, etc.).
** The scaling factor used is the difference between the observed magnitude of concentration exposure and the desired target. For example, if the observed value of concentration exposure is 600 μg/l then a scaling factor of 550 (=600−50) is used to estimate the welfare gain to reduce arsenic concentration level to its safe limit.

not feel compelled to act. However, the current research on the monetary valuation of welfare loss shows the kind of value addition that can result from arsenic removal.

A comparison of benefits generated from arsenic removal with the cost associated with supplying filtered piped water justifies investments in an arsenic-free water supply system in arsenic-affected areas. Currently, the cost of supplying filtered piped water by the Kolkata Municipal Corporation (KMC) to households is approximately Rs 9.44/m^3. Based on a previous socio economic survey based research in the context of Kolkata city we assume on an average consumption of 450 l per household per day, the full O&M cost recovery would impose a cost burden of Rs 127/-month per household (Roy et al., 2004, KMC 2004). This number is lower than the benefits that accrue from consuming arsenic-free water, which we estimate at Rs 297 per month per household. Further, if we compare the benefit and full cost burden on households for installing deep tube wells, we find that the initial cost can be paid back in a maximum of 3 years.

However, some shortcomings to this study need to be discussed in order to highlight the scope for further research in this area. The variable actually used to capture mitigating expenditure is the total medical expenditure on all diseases, which includes arsenic related diseases. Some of the symptoms that are associated with arsenic could have been caused by other diseases as well.

The welfare gain estimates from arsenic removal needs further refinement based on a better understanding of how medical and averting expenditure can change when there is a non-marginal change in arsenic concentration. In view of these limitations, the specification and estimation of the health production function can only be taken as a reasonable first approximation that should be improved upon in future studies.

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Appendix A

Table A1 – Parameter estimates of model for income group I

Model/equation/ Variables Income group I	Expected sign	Parameter value	t-value
EQ1			
Constant		−9.13	−1.16
Nopersick	+	0.88	3.60*
Avert	−	−0.19	−1.44
Tage	+	4.11	1.47
Nonarsd	+	2.03	1.61***
Fz	?	−2.57	−1.16
Hexpa	+	0.05	0.08
R^2	0.47		
EQ2			
Constant		−11.72	
Msickd	+	0.48	2.71*
Avert	−	0.32	1.92**
Mexpf	−	−0.01	−0.05
Tage	+	0.49	0.20
Nonarsd	+	1.79	1.34
Majcau	+	1.58	3.06*
Hexpa	+	1.74	3.10*
R^2	0.42		
EQ3			
Constant		−10.99	−2.84*
Msickd	+	3.53	2.71*
Mmedexp	−	0.14	1.92**
Totedu	+	0.00	0.02
Hexpa	+	0.25	0.84
Mfinc	+	1.15	5.40*
R^2	0.07		

Source: Author's estimates.
*Significant at 1% level of significance.

Table A2 – Parameter estimates of model for income group II

Model/equation/ Variables Income group II	Expected sign	Parameter value	t-value
EQ1			
Constant	?	−69.88	−2.11*
Avert	−	0.14	0.74
Tage	+	1.23	0.47
Nonarsd	+	5.33	5.09*
Fz	?	−5.13	−1.46
Hexpa	+	0.17	0.23
Mfamexp	+	18.57	2.06*
R^2	0.046		
EQ2			
Constant	?	−6.37	−1.97**
Msickd	+	0.65	4.87*
Avert	−	−1.07	−11.26*
Mexpf	−	0.16	0.77
Tage	+	−0.95	−0.91
Nonarsd	+	1.38	1.77**
Majcau	+	0.68	1.56***
Hexpa	+	1.59	3.20*
R^2	0.46		
EQ3			
Constant	?	−3.70	−1.62***
Msickd	+	0.55	3.33*
Mmedexp	−	−0.64	−3.93*
Agr	?	−0.04	−0.19
Majcau	+	0.36	1.13
Hexpa	+	0.98	2.02*
R^2	0.0059		

Source: Author's estimates.
*Significant at 1% level of significance.
**Significant at 5% level of significance.
***Significant at 10% level of significance.

Table A3 – Parameter estimates of model for income group III

Model/equation/ Variables Income group III	Expected sign	Parameter value	t-value
EQ1			
Constant	?	−10.87	−0.76
Nopersick	+	0.48	1.21
Avert	−	0.43	2.45*
Tage	+	2.28	0.38
Nonarsd	+	3.73	1.26
Fz	?	−3.06	−0.49
Hexpa	+	0.73	0.72
EQ2	0.60		
Constant	?	−2.85	−0.43
Msickd	+	1.24	3.94*
EQ2			
Avert	−	−0.71	−6.94*
Mexpf	?	0.17	0.15
Tage	+	−0.01	−0.01
Nonarsd	+	−0.43	−0.28
Majcau	+	1.04	1.03
Hexpa	+	0.94	1.04
EQ3	0.64		
Constant	?	−4.51	−0.64

Table A3 *(continued)*

Model/equation/ Variables		Income group III	
Msickd	+	1.69	4.30*
Mmedexp	-	−1.45	−5.67*
Agr	?	−0.04	−0.07
Majcau	+	1.62	1.08
Hexpa	+	1.46	1.15
R^2	0.09		

Source: Author's estimates.
*Significant at 1% level of significance.
**Significant at 5% level of significance.
***Significant at 10% level of significance.
A majority of parameters are significant at varying levels of significance and barring a few all policy relevant parameters have expected signs. The reason may be a very limited variation in the variables.

REFERENCES

Adair, Blakely M, Schmitt, Michael T, Calderon Rebecca, Thomas David J. Total arsenic concentrations in toenails quantified by two techniques provide a useful biomarker of chronic arsenic exposure in drinking water. J Environ Res 2006;101(2).

Ahmad J, Goldar BN, Misra S, Jakariya M. Fighting arsenic, listening to rural communities: willingness to pay for arsenic-free, safe drinking water in Bangladesh. www.wsp.org/publications/sa_arsenic_learning.pdf; 2002.

Central Ground Water Board. (JulyHigh Incidence of Arsenic in Ground Water in West Bengal, Ministry of Water Resources. Government of India; 1999.

Chakraborti AK, Saha KC. Arsenic dermatoses from tube-well water in West Bengal. Indian J Med Res 1987;85:326–34.

Chakraborti D, Basu GK, Biswas BK, Chowdhury UK, Rahman MM, Paul K, et al. Characterization of arsenic bearing sediments in gangetic delta of West Bengal, India. In: Chappell WR, Abernathy CO, Calderon RL, editors. Arsenic Exposure and Health Effects. New York: Elsevier Science; 2001. p. 27–52.

Chowdhury UK, Biswas BK, Roy Chowdhury T, Samanta G, Mandal BK, Basu GK, et al. Groundwater arsenic contamination in Bangladesh and West Bengal, India. Environ Health Perspect 2000;108:393–7.

Commission on Life Sciences. Arsenic in Drinking Water; 1999.

Courant PN, Porter RC. Averting expenditure and the cost of pollution. J Environ Econ Manage 1981;8:321–9.

Cropper ML. Measuring the benefits from reduced morbidity. Am Econ Rev 1981;71:235–40.

Dang HS, Jaiswal DD, Somsundaram S. Distribution of arsenic in human tissues and milk. Sci Tot Environ 1983;29:171–5.

Das D, Chatterjee A, Samanta G, Mandal B, Chowdhury TR, Samanta G, et al. Valuing health damages from water pollution in urban Delhi, India: a health production function approach. Arsenic contamination in groundwater in six districts of West Bengal, India: the biggest arsenic calamity in the world Dec 1994;119(12):168N–70N.

Das D, Samanta G, Mandal BK, Chowdhury TR, Chanda CR, Chowdhury PP, et al. Arsenic in ground water in six districts of West Bengal, India: biggest arsenic calamity in the world. Environ Geochem Health 1996;18:5–15.

Dasgupta P. Valuing health damages from water pollution in urban Delhi, India: a health production function approach. Environ Dev Econ 2004;9:83–106.

Table A4 – Confidence interval estimates of MWTP/welfare gain

Welfare gain	Income groups: Income<=2000		Income >2000<=60,000		income>6000		Pool	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Monthly welfare gain from reduction of arsenic concentration by 1 μg/l (Rs)	−0.26	1.15	0.12	1.92	0.21	7.09	−0.01	4.80
(Point estimate)	0.56 (0.30)		1.02 (0.46)		3.65 (1.66)		2.39 (1.23)	
Monthly welfare gain from reduction of arsenic concentration to safe limit of 50 μg/l (Rs)	−46.18	761.01	−30.15	1206.39	−205.96	4303.5	−126.45	3026.27
(Point estimate)	357.42 (205.92)		588.12 (315.45)		2048.77(1089.77)		1449.91 (804.26)	
Annual welfare gain from reduction of arsenic concentration by 1 μg/l (Rs)	−0.32	13.74	1.45	22.99	2.57	85.11	−0.12	57.58
(Point estimate)	6.71(3.58)		12.00 (5.49)		43.84 (19.91)		28.73 (14.72)	
Annual welfare gain from reduction of arsenic concentration to safe limit of 50 μg/l (Rs)	−554.21	9132.20	−361.83	14473.76	−2471.54	51642.05	−1517.45	36317.28
(Point estimate)	4289.8 (2471.02)		7057.00 (3785.35)		24585.25 (13077.23)			

Freeman AM. The Benefits of Environmental Improvement. Baltimore: Johns Hopkins University; 1993.
Gerkin S, Stanely L. An economic analysis of air pollution and health: case of St. Louis. Rev Econ Stat 1986;68:115–21.
Garai R, Chakraborty AD, Dey SB, Saha DC. Chronic arsenic poisoning from tube-well water. J Indian Med Assoc 1984;82:34–5.
Guha Mazumdar DN. Clinical aspects of chronic arsenic toxicity. J Assoc Phys India 2001;49:650–5.
Guha Mazumdar DN, Ghose A, Pal NC, Mukherjee J, Guha Ray BN. Search for aetiological factors of non-cirrhotic portal fibrosis. Indian J Gastroenterol 1984;3:25–6.
Guha Mazumder DN, Chakraborty AK, Ghose A, Gupta JD, Chakraborty DP, Dey SB, et al. Chronic arsenic toxicity from drinking tube well water in Rural West Bengal. Bull WHO 1988;66(4):499–506.
Guha Mazumder DN, Haque R, Ghosh N, De BK, Santra A, Chakraborty D, et al. Arsenic levels in drinking water and the prevalence of skin lesions in West Bengal, India. Int J Epidemiol 1998;27:871–7.
Guha Mazumder DN, Haque R, Ghosh N, De BK, Santra A, Chakraborty D, et al. Arsenic in drinking water and the prevalence of respiratory effects in West Bengal, India. Int J Epidemiol 2000;29(6):1047–52.
Gupta Usha. Valuation of Urban Air Pollution: A Case Study of Kanpur City in India. SANDEE Working Paper No 17-06; 2006.
Grossman M. On concept of health capital and the demand for health. J Polit Econ 1972;80:223–55.
Harrington Winston, Portney Paul R. Valuing the benefits of health and safety regulation. J Urban Econ 1987;22:101–12.
Jalan, Jyotsna, Somanathan, E., and Choudhuri, S. (2003), “Awareness and the Demand for Environmental Quality: Drinking Water in Urban India”, Working Paper no. 4-03, SANDEE, Kathmandu, Nepal.
Kolkata Municipal Corporation. Purabarta, No. 10, July, Kolkata; 2004.
Murty MN, Gulati SC, Banerjee A. Health benefits from urban air pollution abatement in the Indian subcontinent. Working Paper No. E/236/2003. Delhi-110007, India: Institute of Economic Growth; 2003.
Rahman MM, Mandal BK, Roy Chowdhury T, Sengupta MK, Chowdhury UK, Lodh D, et al. Arsenic groundwater contamination and sufferings of people in North 24-Parganas, one of the nine arsenic-affected districts of West Bengal, India: the seven year study report. J Environ Sci Health, 2003;A38(1):27–59.
Roy Joyashree, Sahu Sohini. Willingness to pay studies: a policy tool. Paper Presented at the Conference on Market Development of Water and Waste Technologies through Environmental Economics, 5-7 May, Paris; 2004. http://www.cerna.ensmp.fr.
Roy Joyashree, Subhorup Chattopadhyay, Sabyasachi Mukherjee, Manikarnika Kanjilal, Sreejata Samajpati, Sanghamitra Roy. An economic analysis of demand for water quality: a case from Kolkata City. Econ Polit Wkly 2004;XXXIX.2:186–92.